CAAP Quarterly Report

Date of Report: 3/8/2021

Prepared for: *U.S. DOT Pipeline and Hazardous Materials Safety Administration*

Contract Number: 693JK32050004CAAP

Project Title: Probabilistic Performance Modeling and Optimum Maintenance Planning of Plastic Pipeline with Piezoelectric Based NDE Updating

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For quarterly period ending: 12/1/2020 - 2/28/2021

Business and Activity Section

(a) Contract Activity

The subcontract to University of Akron need be changed to Marquette University since Dr. Qindan Huang (Co-PI) has changed the institution after the proposal was submitted. The PI will submit the request of change to PHMSA and process the subcontract after the approval.

(b) Status Update of Past Quarter Activities

The research team started working on task 2 that aims to develop the experimental setup for piezoelectric-based sensing system. The PhD student, Said El-Hawwat, worked on the setup of data generation and acquisition system and debugged the wave generation function with LabVIEW program.

(c) Cost Share Activity

Cost share is provided during this quarterly period as budgeted in the proposal.

(d) Technical Approach

Experimental Setup

The high-density polyethylene (HDPE) pipe was purchased for trial experiments. In the experimental setup, the HDPE pipe is loaded with vibration waves generated by a Sound and Vibration Device (bus-powered USB 4331 from National Instrument), augmented by an amplifier, emitted and received by a pair of Macro Fiber Composite (MFC) transducers, and controlled by LabVIEW software. The USB-4431 device has sampling rates between 1 kS/s to 102.4 kS/s (kS/s represents kilosamples per second), equipped with four input connectors for simultaneously receiving voltage signals. The response wave is collected by an oscilloscope (EDUX1002A). The EDUX1052 oscilloscope has a 50 MHz bandwidth with a 1 GS/s sample rate (GS/s represents gigasamples per second). Such 50 MHz bandwidth shall be sufficient to find the proper frequency bandwidth for the purpose of pipeline health monitoring sought in this study. The illustration of testing apparatus is shown in Figure 1.

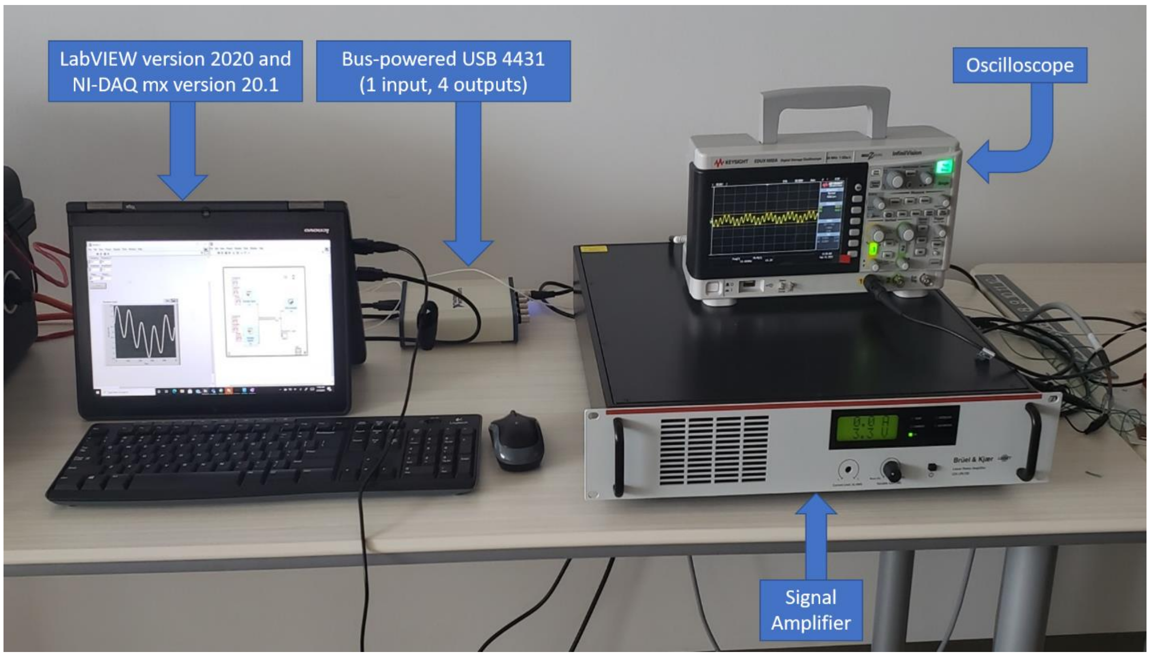
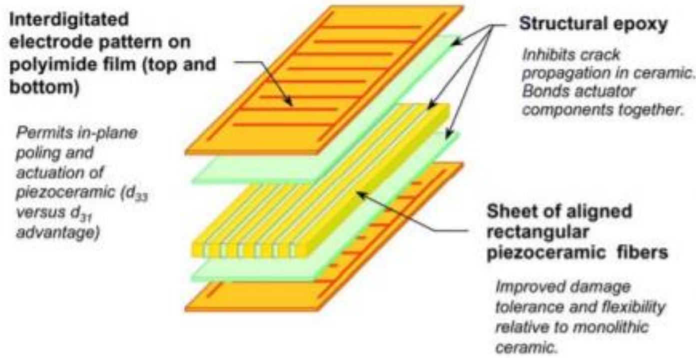
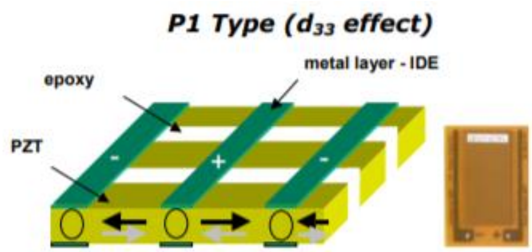


Figure 1 Testing Apparatus

Macro-fiber-composite (MFC) is a composite material made up of five layers including piezoceramic fibers, structural epoxy, and polyimide film, as shown in Figure 2(a). The MFC enables actuation and sensing in a sealed, durable, ready-to-use package and it contains interdigitated electrodes. The specific piezoelectric transducer selected for either emitting or receiving signals is P1-type MFC transducer with the size of 14 mm × 28 mm (model M-2814-P1), as shown in Figure 2(b). The electrodes of MFC transducer are connected with very fine wire (30 AWG wire) using silver epoxy adhesive, as shown in Figure 3.



(a)



(b)

Figure 2 Illustration of MFC composition and P1 type MFC with d33 effect

(http://www.smart-material.com)


Figure 3 Macro-Fiber Composite based transducer

In order to properly test the plastic pipe, the two ends of the HDPE pipe are fixed. This is accomplished through the use of C-clamps. One clamp is attached at each end of the HDPE pipe, and two clamps together fix the pipe to the table, as shown in Figure 4.

Two MFC transducers are tightly bonded to pipeline surfaces by cyanoacrylate superglue, and bent to seamlessly fit the surface curve without damage. The flexibility and in-plane poling of MFC make it ideal transducers for the purposes of this project. MFC transducers can behave as both actuators and sensors. As such, they will be utilized in conjunction with the LabVIEW program to provide both input and output signals

Figure 4 Fixed-ends of plastic pipe with MFC transducers

Figure 5 summarizes the procedure by which the signal is generated, transmitted, and received for the purpose of piezoelectric-based monitoring.

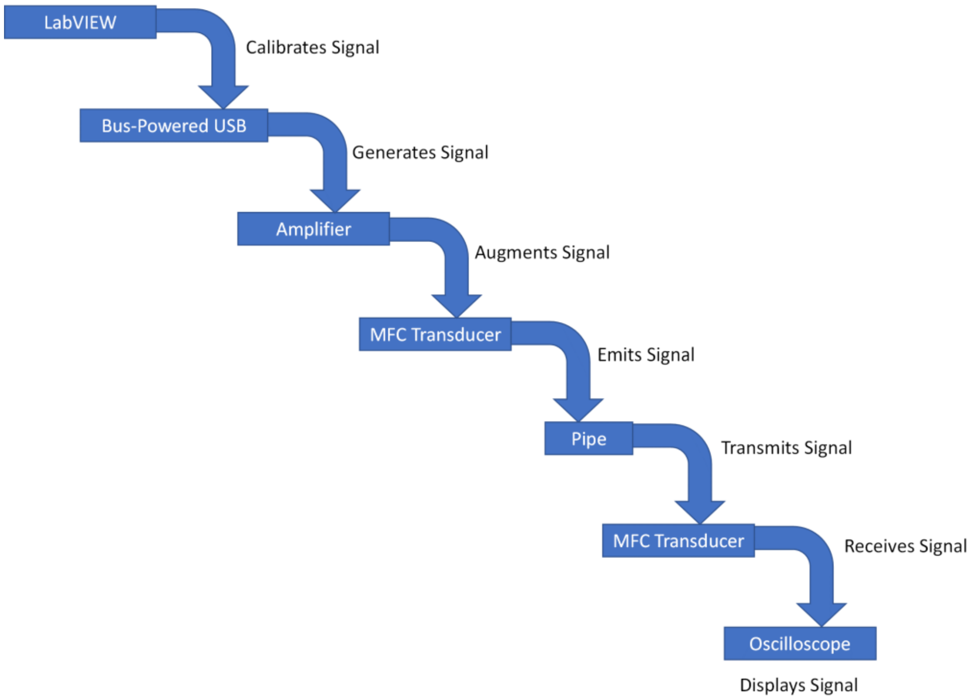


Figure 5 Signal Generation and Transmission Flowchart

Wave Function Generation

The LabVIEW program is used to generate wave function for sensor actuation. Figure 6 shows the Front Panel of the LabVIEW software, and Figure 7 shows the Block Diagram. This setup requires the installment of NI-DAQ mx (National Instruments' data acquisition software) in order to run successfully. Using the apparatus, complex signals which are the summation of two separate signals may be generated.

As can be seen in the block diagram setup, the generated signal is in fact the sum of two simulated signals. Each simulated signal has been wired to the input of an addition structure. The addition output is, in turn, wired to the wave generation structure provided by NI-DAQ mx. In order for the signal to be generated continuously, the entire Block Diagram setup is encased in a while loop, with the stopping criteria that the generation ends if the STOP button in the Front Panel is pushed. Furthermore, controls have been created to allow each simulated signal's amplitude, frequency, and phase to be toggled by the user in the Front Panel. The Front Panel shows a waveform graph which portrays the signal amplitude (voltage) vs. time. Finally, a sampling control is included. This allows the user to toggle the sampling rate with respect to time.

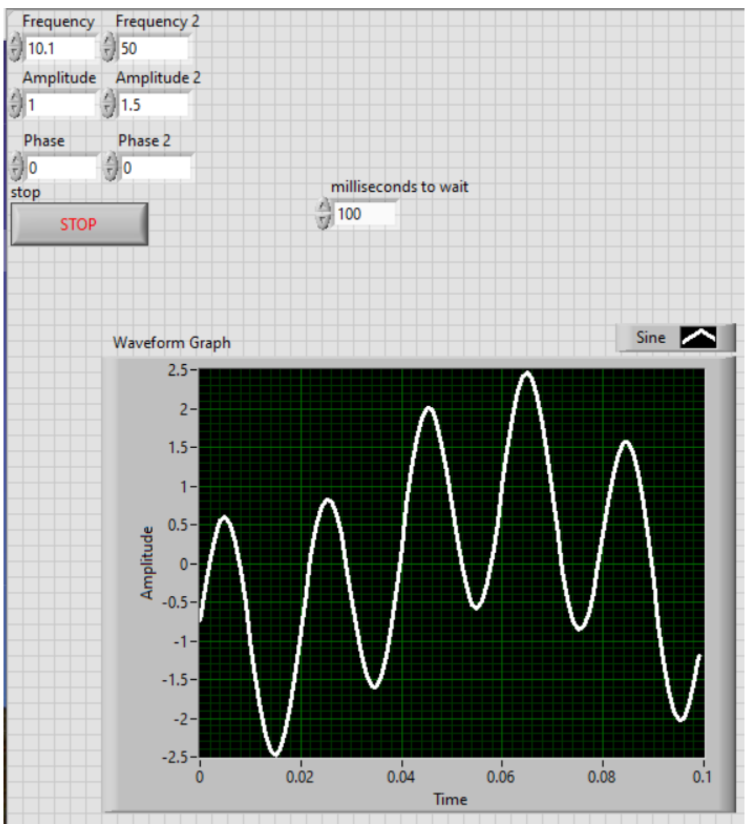


Figure 6 LabVIEW Program Front Panel

The bus-powered USB can only accept generated signals with amplitudes between -3.5 and 3.5 volts. Thus, the NI-DAQ mx structure will provide an error message if the sum of the simulated signals ever takes a value above 3.5 volts or below -3.5 volts. This limit is not so inconvenient, as the amplifier allows for multiplication of the signal magnitude by a constant, thus providing vibrational waves which better simulate in-service exposures.

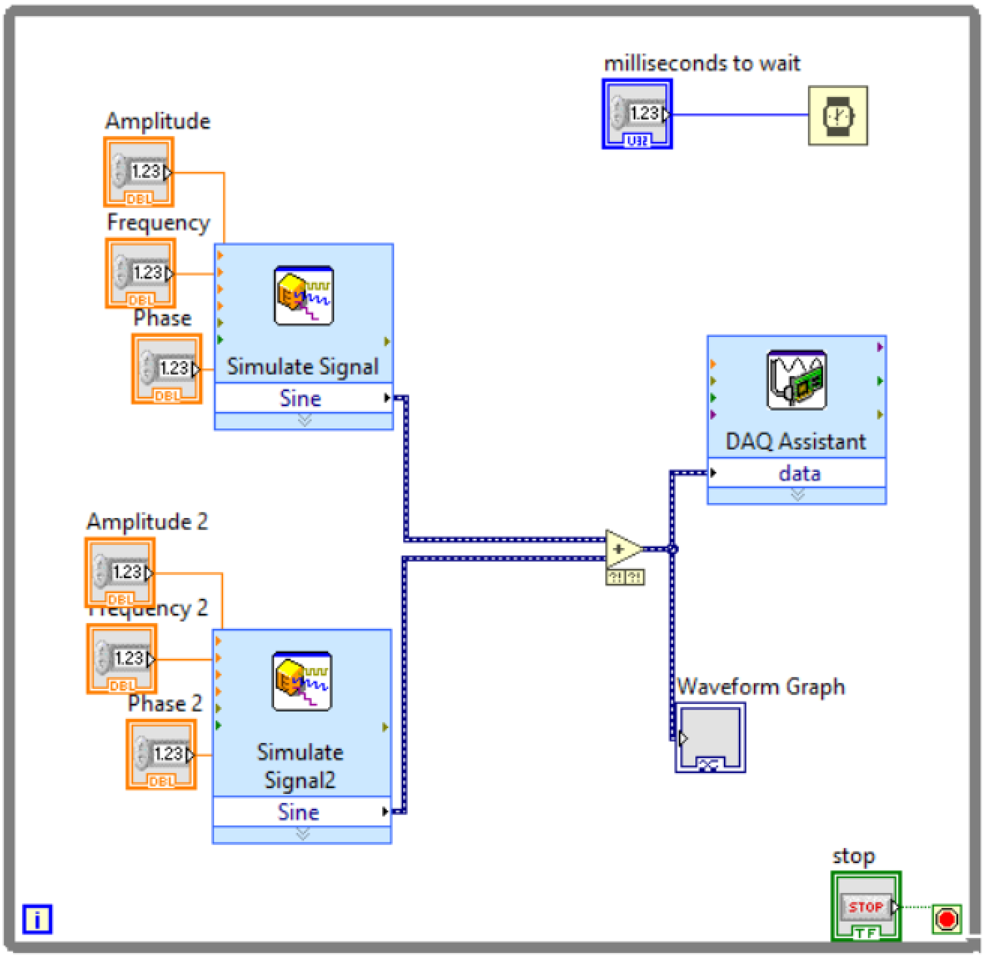


Figure 7 LabVIEW Program Block Diagram

A sweep signal generator experiment is conducted in LabVIEW in order to obtain the desired frequency range of the actuator. The front panel of the program is in Figure 8, and the block diagram is in Figure 9.

This program examines the frequency range of a transducer for a provided sampling rate (here 50,006 samples per channel per second). The tone measurements function calculates frequency for a single tone in Hertz. Upon running the software for a time, the useful frequency range appeared to be between 45 and 75 Hz. The following setup will utilize signals with frequencies in the useful frequency range of the actuator to acquire a strong response.

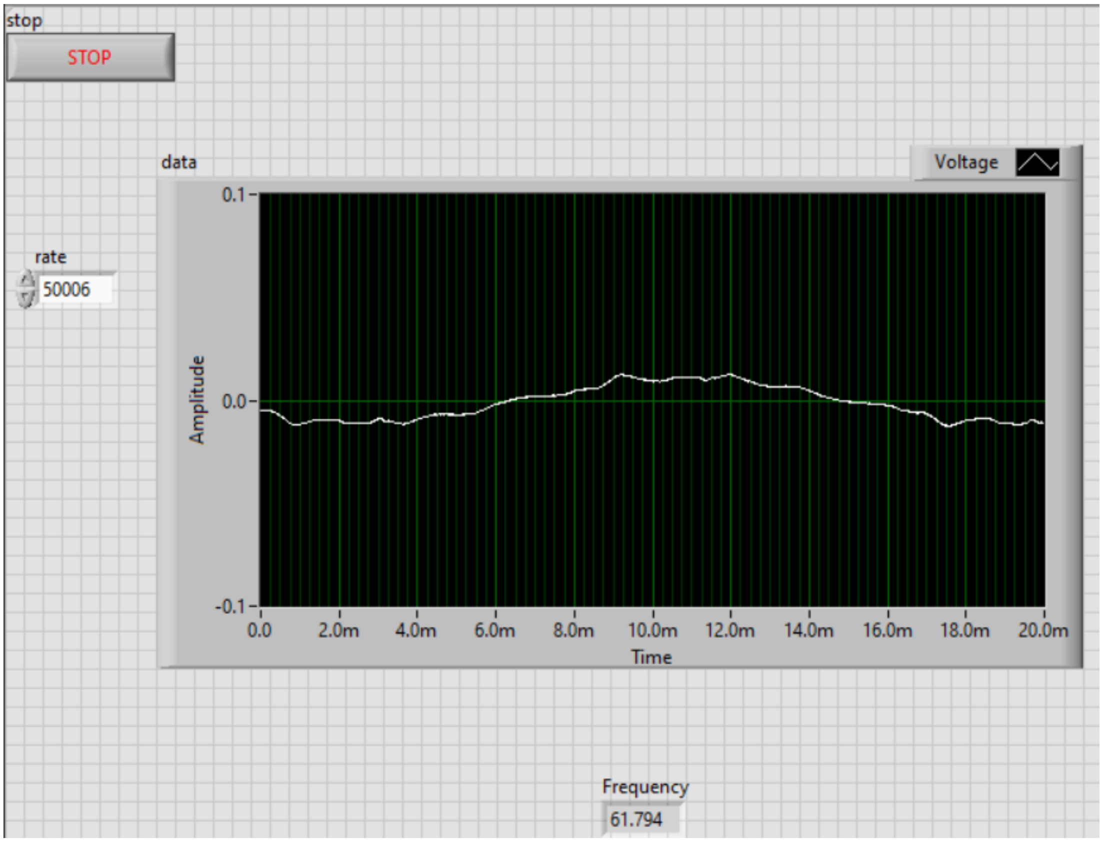


Figure 8 Sweep Signal Experiment Program Front Panel

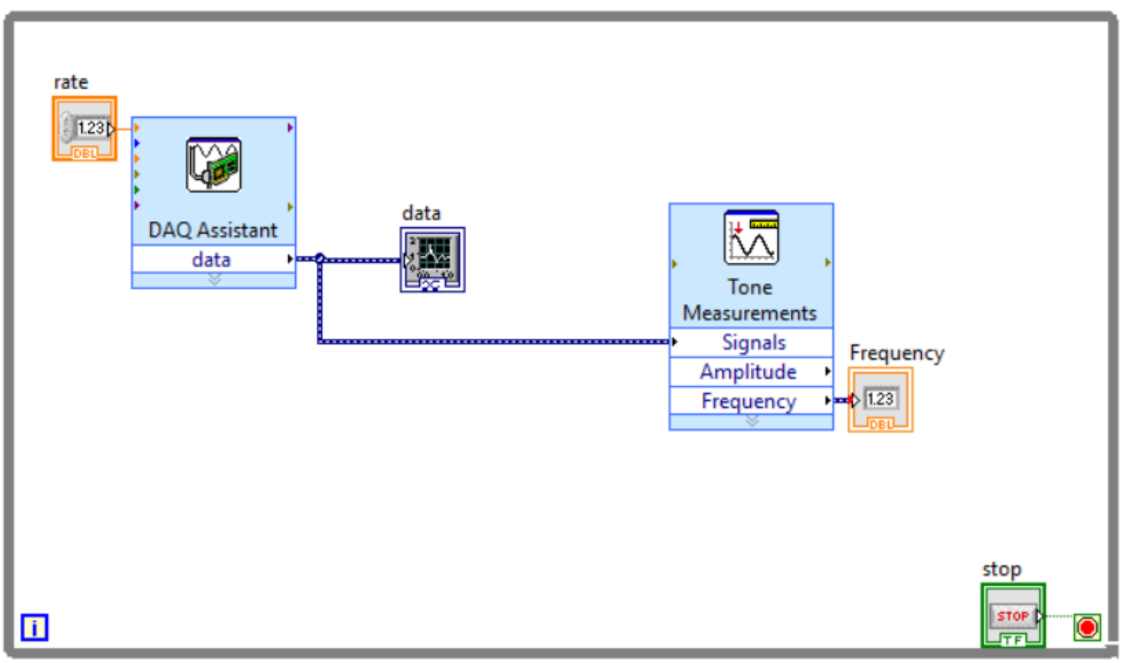


Figure 9 Sweep Signal Experiment Program Block Diagram

Gaussian Modulated Sinusoidal Function

A useful excitation signal for crack detection is one which attenuates over time. One such signal is the Gaussian Modulated Sinusoidal. This function is defined by the following equations.

$$y_i = A\mathrm{e}^{-k(\mathrm{i}\Delta t\cdot d)^2}\cos\big(2\pi f_c(i\Delta t - d)\big)$$

$$\text{with } k = \frac{5\pi^2 b^2 f_c^2}{q\ln(10)}$$

Where, $i = 0, 1, 2, \ldots, N\text{-}1$, A is the amplitude (V), b is the normalized bandwidth, q is the attenuation (dB), f_c is the central frequency (Hz), d is the delay (s), and N is the samples.

The Gaussian Modulated Sinusoidal used for the purposes of the experiment has a central frequency of 50 Hz, which is within the useful frequency range of the actuator. The signal is shown in the front panel in Figure 10. This program's block diagram is in Figure 11. The sampling rate is 1 ms^{-1}. A delay of 0.065 s, amplitude of 3 volts (before amplification), and normalized bandwidth of 0.17 have all been specified.

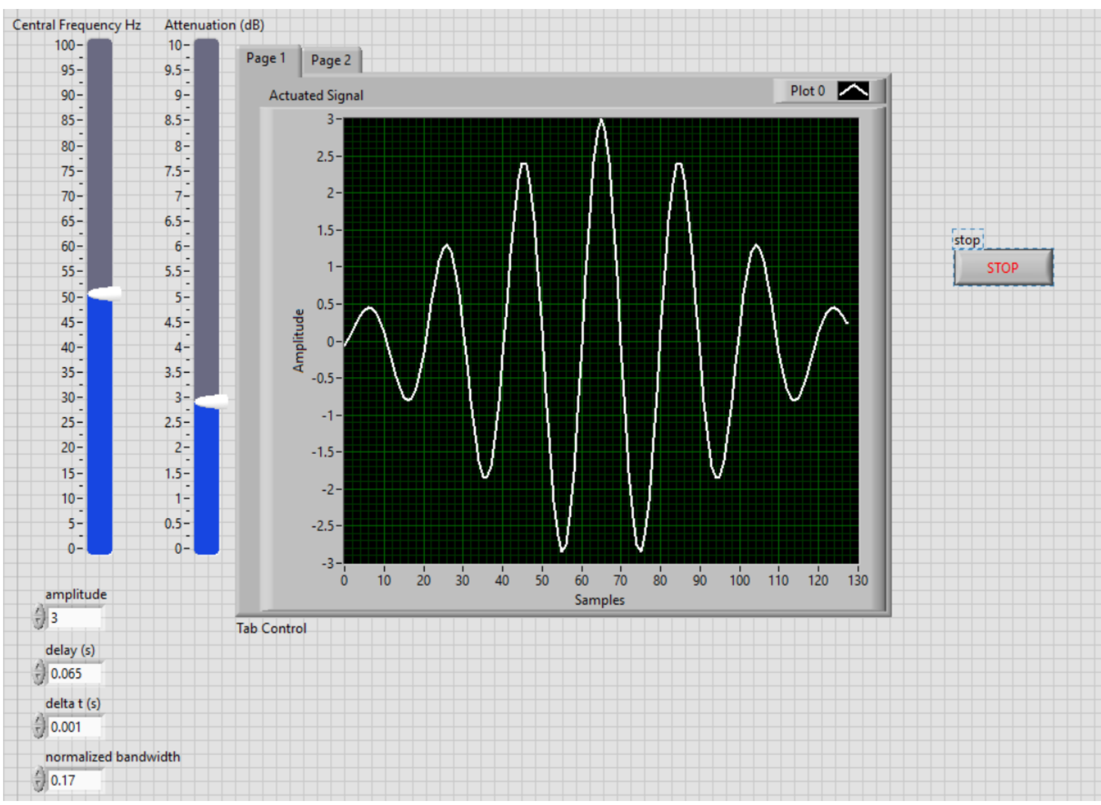


Figure 10 Gaussian Modulated Sinusoidal Excitation Signal Front Panel

As is apparent in the block diagram, all the controllable attributes of the sinusoidal are wired to a Gaussian Modulated Sine Pattern function. The central frequency and attenuation may be toggled by a slider control, and the other attributes are specified by numeric controls. This allows the user to easily examine the program for multiple central frequency values in the actuator's useful frequency range.

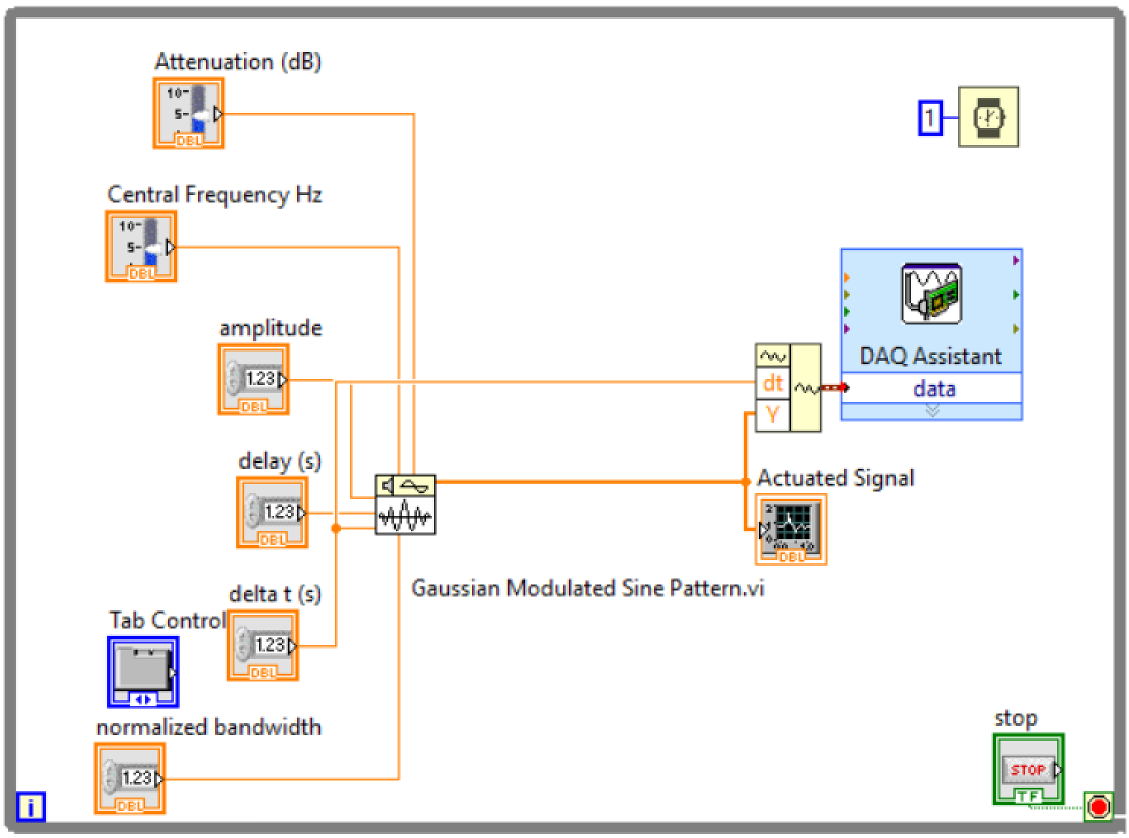


Figure 11 Gaussian Modulated Sinusoidal Excitation Signal Block Diagram